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Primary reverse shoulder replacement with a short stem: A systematic literature review

Anna K. Tross, MD [a,b], Thomas E. Woolson, BA [a], Philip C. Nolte, MD, MA [a,c], Marc Schnetzke, MD [c,d], Markus Loew, MD [d], Peter J. Millett, MD, MSc [a,e,*]

[a] Steadman Philippon Research Institute, Vail, CO, USA
[b] Heidelberg University Hospital, Clinic for Orthopedics and Trauma Surgery, Heidelberg, Germany
[c] BG Trauma Center Ludwigshafen at the University of Heidelberg, Clinic for Trauma and Orthopaedic Surgery, Heidelberg, Germany
[d] German Joint Centre, ATOS Clinic Heidelberg, Heidelberg, Germany
[e] The Steadman Clinic, Vail, CO, USA

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Background: Total shoulder arthroplasty implant designs have continued to evolve over the years. One recent change has been the shortening of the humeral component to preserve bone stock and to facilitate revision surgery. Despite promising clinical results, radiographic bone adaptions occur frequently in short-stem total shoulder arthroplasty, and limited data exist on short-stem reverse shoulder arthroplasty (RSA). The purpose of this systematic review was to provide an overview about the functional and radiographic outcomes after an uncemented short-stem RSA, as well as identify areas of clinical importance that are underreported in the current literature.

Methods: A systematic review of the literature was performed in accordance with the PRISMA guidelines using PubMed, Cochrane Central Register of Controlled Trials, and EMBASE. Clinical outcome studies reporting on short-stem RSA outcomes with evidence level I-IV were included. Demographics, clinical and radiological outcomes, as well as complications and revision data were systematically analyzed and described.

Results: Ten studies, published between 2014 and 2019, reporting on 555 shoulders with a mean follow-up of 32 months (range, 20-99.6 months) met the inclusion criteria. For all studies cuff tear arthropathy was the main indication for RSA (36%), followed by primary osteoarthritis (20%). Clinical outcome was reported in nine of ten studies, with range of motion improving in all studies. Six of the seven studies that used the Constant score (CS) demonstrated significant improvement (27.9 points to 69.3 points in weighted means). All studies reported on radiographic changes and bone adaptions. Among these, scapular notching was the most commonly observed (60 out of 327 cases, 18%) but without any described implication on clinical outcomes. No stem loosening was recorded at any final follow-up. A total of 63 complications (12.9%) were reported, with scapula fractures being the most commonly reported complication. Revision surgery was necessary in 24 cases (4.9%).

Conclusion: Good clinical results, comparable with long-stem RSAs, are reported at short-term follow-up for short-stem RSAs. Humeral bone adaptions occur frequently but aseptic stem loosening is not a matter of concern at short-term follow-up. An area of clinical importance that is under-reported is the relation between filling ratio and stem alignment in short-stem RSA.

Reverse shoulder arthroplasty (RSA) is an option to treat patients diagnosed with complex shoulder pathologies. This includes patients with rotator cuff arthropathy who have failed conservative treatment[39,59] or patients who have failed total shoulder arthropathy (TSA) and require revision RSA.[17] In 1985, Grammont developed the *Delta Shoulder Prosthesis* as he pioneered a "nonanatomic" approach to shoulder reconstruction, an RSA.[6] His prosthesis would be used as a prototype for all modern RSA designs.[7,22] Recent publications have shown an increased complication rate in the long-term follow-up (FU) of Grammont-type RSA with a traditional long stem, with complications such as humeral fractures and aseptic stem loosening having a negative impact on functional outcomes.[3]

Revision surgery after primary shoulder arthroplasty can become necessary in cases of aseptic humeral component

Institutional review board approval was not required for this systematic review.

* Corresponding author: Peter J. Millett, MD, MSc, Steadman Philippon Research Institute, The Steadman Clinic, 181 W Meadow Dr, Ste 400, Vail, CO 81657, USA.

E-mail address: drmillett@thesteadmanclinic.com (P.J. Millett).

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loosening, fracture, dislocation, or infection.[3,10,16,17,23] However, removing a well-fixed long-stem humeral component can be challenging with the risk of iatrogenic fractures and potential bone loss due to extensive bone ingrowth.[16,44,50,55,58,59] Shortening the humeral component of the implant is one-way surgeons have tried to preserve bone stock and make revision surgery easier.[14,26,32,47] Recently, reverse short-stem prostheses[1,19] as well as convertible short-stem prostheses for RSA have entered the market.[48]

Present studies have shown promising short- and medium-term clinical results following short-stem TSA.[12,43,46,49] Despite these encouraging results, radiographic bone adaptions such as radiolucent lines,[43,46] cortical thinning,[12,45] osteopenia, spot welds,[45] partial calcar osteolysis,[12,43] stem loosening or stems judged at risk for loosening[37] at short-term FU as well as substantial bone loss at mid-term FU[49] have been described. Compared with short-stem TSA,[14,47] outcome data for primary uncemented short-stem RSA is limited.

The purpose of this systematic review was to provide an overview about the functional and radiographic outcomes after an uncemented short-stem RSA, as well as identify areas of clinical importance that are underreported in the current literature. The authors hypothesized that short-stem RSA will lead to similarly good clinical and radiological outcomes as the more common long-stemmed RSA surgery, with low revision rates.

Methods

A systematic literature search was conducted on March 3rd, 2020, following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The systematic literature review was based on the combination of three databases (PubMed, Cochrane Central Register of Controlled Trials, and EMBASE) to reach the highest recall rates.[54] Two reviewers (AKT and TEW) performed the initial study identification, secondary study screening, final determination of study inclusion and data extraction independently. In the event of disagreement, the studies were discussed with a third author (PCN) and a consensus was reached. The electronic search algorithm was slightly adapted to the databases' requirements to reach the most possible results: PubMed: *(((((shoulder) AND (short stem)) AND (reverse)) OR (inverse)) AND (shoulder)) AND (short stem), EMBASE: ('shoulder'/exp OR shoulder) AND short AND ('stem'/exp OR stem) AND reverse, Cochrane: shoulder in Title Abstract Keyword AND short stem in All Text AND reverse in All Text.*

Inclusion criteria were defined as the following: primary implantation of a cemented or uncemented short-stem RSA, evidence level I-IV, FU minimum >12 months. Exclusion criteria were non-English language studies, review articles, case reports, medical conference abstracts, cadaveric or animal studies, biomechanical studies, imaging studies, and surgical technique studies.

After the exclusion of titles and abstracts, full-text articles were manually reviewed. To ensure that all the relevant studies were included, reference lists from the all the remaining studies were analyzed. The studies were screened for duplicate patient populations. In studies that compared different implant designs, such as short-stem TSA with short-stem RSA, only the short-stem RSA outcomes were reported on. In studies that reported FU times for both intervention groups, the FU time was reported for the RSA group alone. Various indications for RSA were included. Considerations, exclusion and inclusion steps can be identified through the demonstrated flow chart (Fig. 1).

Demographic data were collected systematically. Primary endpoints were clinical outcome (range of motion [ROM], pain, and outcome scores), radiographic outcome (humeral bone adaptions, scapular notching, and component loosening), complications, and revision rates. The Methodological Index for Non-Randomized Studies (MINORS) tool for nonrandomized studies was used to evaluate the methodology of each study (Table I).[53]

Statistical analysis

Grouped analysis was only applied if a single variable was reported in ≥ 2 studies. To report about the overall complication and revision rates pooling was performed for categorical variables. When possible, weighted means were calculated in Excel 2020 (Version 16.35, Microsoft, WA, USA) for continuous variables based on the total amount of shoulders per study.

Results

As demonstrated in Figure 1, ten of 62 studies met the inclusion criteria. Nine of ten studies were case series without a comparison group (level IV treatment studies); one study met the criteria for a retrospective comparative study (level III treatment study). All studies were published between 2014 and 2019 with 4 studies from France, Germany, and Italy in the Journal of Shoulder and Elbow Surgery, two studies from France in the Journal of Shoulder and Elbow Arthroplasty, one German study in the Archives of Orthopaedic and Trauma Surgery, one study from the United Kingdom in the Journal of the Société Internationale de Chirurgie Orthopédique et de Traumatologie, and two studies from the United States in the Bone and Joint Journal. Eight study groups had at least one author who declared a financial conflict of interest.

Implants and surgical technique

RSAs were performed using four different uncemented short-stem implant designs in the included studies: Ascend Flex (Fa. Wright Medical, Bloomington, MN, USA), Comprehensive Reverse Shoulder System Mini Stem (Fa. Zimmer-Biomet, Warsaw, IN, USA), Comprehensive Reverse Shoulder System Micro Stem (Fa. Biomet, Swindon, UK), and Verso Reverse Shoulder Prosthesis (Biomet, Swindon, UK).

All listed stems have a stem length below 100 mm and comprise titanium with proximal porous surface coating. Although all included study groups aimed to implant the listed prostheses in an uncemented fashion, in some cases, cementation was necessary. Three study groups included a total of 31 cemented short-stems due to poor bone stock or insufficient rotational stability.[2,20,36] These cases were included. In 443 (80%) of the cases, a deltopectoral approach to the shoulder joint was used, whereas the remaining 112 (20%) cases used a superior approach. The glenoid was fixed uncemented with locking screws in 334 cases as reported in 6 studies[2,13,20,35,42,48] and with a press-fit short- or long-pegged glenoid implant in 81 cases reported by one study.[40] A bony increased offset technique that uses the humeral head as autograft (Bio-RSA) according to Boileau et al[8] was used in 123 (22%) reported cases.

Demographics

About 555 shoulders in all ten studies were enrolled between 2005 and 2016, with a weighted mean FU of 32 months (range, 20 to 99.6) (Table II).

The Ascend Flex (Fa. Wright Medical, Bloomington, MN, USA) was used predominantly in seven of ten studies. Four study groups assessed the early clinical and radiological results after implanting the Ascend Flex System in cases of primary RSA: Schnetzke et al[48] included 24 shoulders, a large case series with 100 shoulders was presented by Ascione et al[2] and two multicenter studies by

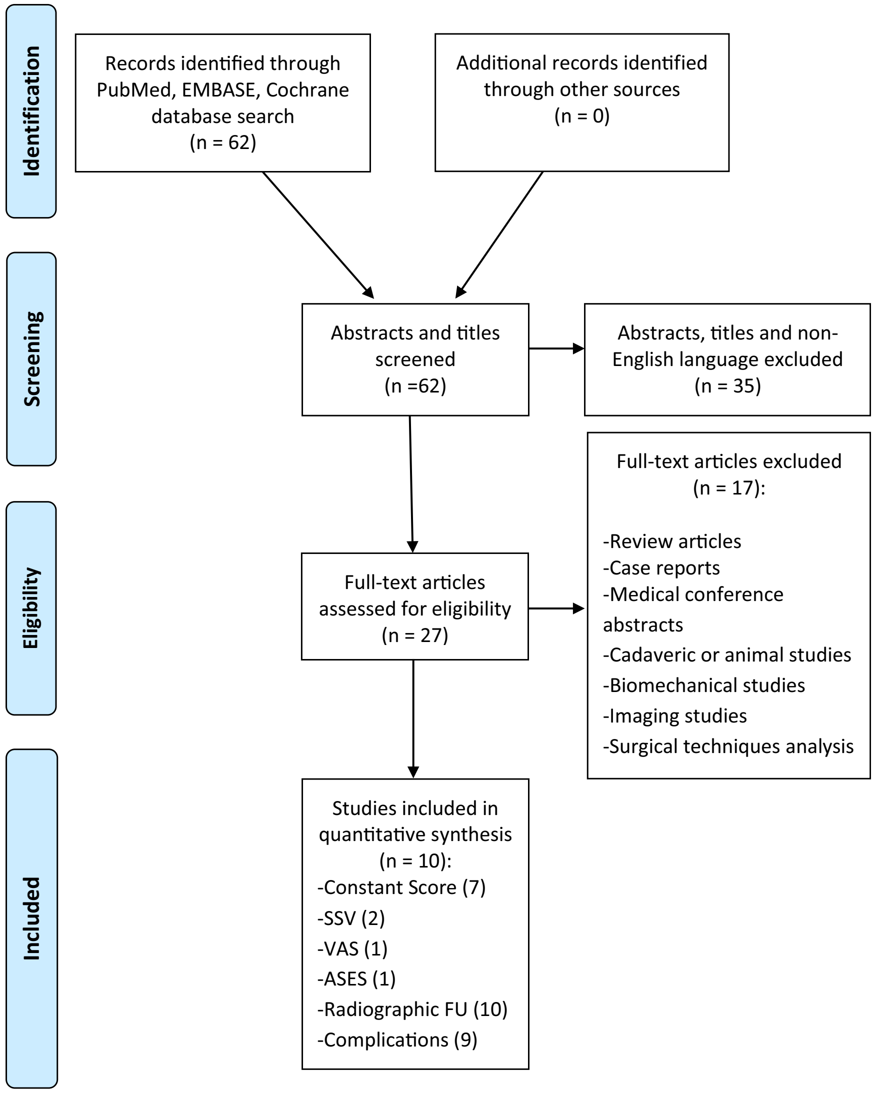

Figure 1 PRISMA flow diagram of study selection.

Goetzmann et al[20] and Merolla et al[36] examined 24 and 38 shoulders, respectively. The same prosthesis was tested by Peduzzi et al[40] in 81 cases, by Raiss et al[42] in 77 cases, and by Dukan et al[13] in 71 cases of primary short-stem RSA. In 2014, Giuseffi et al[19] reported about the safety and early complication rate after RSA with a Mini Stem (Biomet, Warsaw, Indiana) in 44 shoulders. Aibinder et al[1] recently tested the same Comprehensive Reverse System but with an even shorter uncemented Micro stem (Biomet, Warsaw, IN, USA) in 65 shoulders. In 2014, Atoun et al[5] used a short-stem (Verso, Biomet, Swindon, UK) in 31 primary cases of primary short-stem RSA.

The most common indication for primary RSA in these studies was cuff tear arthropathy (CTA) in 202 cases (36%). CTA was preoperatively classified according to Hamada et al[25] by three studies. Hamada grades 4 and 5 had the highest ratio among the included studies.[2,13,36] Other indications included primary osteoarthritis (20%), CTA or osteoarthritis in combination with full-thickness rotator cuff tears or massive glenoid erosion (14%), glenohumeral arthritis with deficient cuff muscle (13%), osteoarthritis with irreparable rotator cuff tear (5%), massive rotator cuff tears (3%), posttraumatic sequelae (3%), primary osteoarthritis with glenoid bone loss (1%), avascular necrosis (1%), post-traumatic arthritis (1%), rheumatoid arthritis (1%), avascular necrosis (1%), inflammatory arthropathy (1%), and instability arthropathy (<1%). One study group did not subclassify their indications and basically described their indication for RSA as "cuff tear arthropathy or osteoarthritis of glenohumeral joint in combination with full-thickness rotator cuff tears or massive glenoid erosion".[42]

Clinical outcome

Clinical outcome was reported in nine of ten studies, accounting for 478 shoulders and a mean FU of 33 months (range, 20 to 99.6) (Table III). One study group did not determine clinical outcome parameters for short-stem RSA separately[42] and the results were therefore not included.

Improvement of ROM was reported in all studies with a significant improvement reported by seven studies.[1,2,13,20,36,40,48] Preoperative flexion improved in weighted means from 76° to 134° at final FU. External rotation improved in weighted means from 15° to 32° at final FU. Abduction was only assessed in five of ten studies and improved in weighted means from 68° to 119° at final FU. Internal rotation was not measured homogeneously and was therefore not described in this review.

Table I
Quality scoring of study selection based on the Methodological Items for Non-Randomized Studies (MINORS) criteria.

Study	1	2	3	4	5	6	7	8	9	10	11	12	MINORS score
Giuseffi (2013)[19]	2	0	0	2	0	2	0	0	0	0	0	0	6/16
Atoun (2014)[5]	2	1	0	2	0	2	1	0	0	0	0	0	8/16
Ascione (2017)[2]	2	0	0	2	0	2	1	0	0	0	0	0	7/16
Goetzmann (2017)[20]	2	2	0	2	0	2	1	0	1	2	1	2	15/24
Schnetzke (2017)[48]	2	1	2	2	2	1	2	0	1	2	1	2	18/24
Merolla (2017)[36]	2	2	0	2	2	2	1	1	2	2	1	2	19/24
Aibinder (2019)[1]	2	1	2	2	0	2	2	0	1	2	1	2	17/24
Dukan (2019)[13]	2	2	2	2	0	2	1	0	0	0	0	0	11/16
Raiss (2019)[42]	2	2	0	2	0	2	1	0	1	2	1	2	15/24
Peduzzi (2019)[40]	2	2	0	2	0	2	1	0	1	2	1	2	15/24

Table II
Demographics from selected short-stem RSA studies.

Study	Prosthesis type	Shoulders, n	Age (range)	Male sex, n (%)	Female sex, n (%)	Dominant side, n (%)	Indication for RSA
Giuseffi (2013)[19]	Comprehensive Reverse System Mini Stem	44	76 (59-92)	15 (34)	29 (66)	NR	RCA (33), AVN (6), PTA (2), inflammatory arthropathy (3)
Atoun (2014)[5]	Verso Reverse Shoulder Prosthesis	31	73,5 (58-93)	10 (32)	21 (68)	NR	RCA (22), fracture sequelae (5), RA (4)
Ascione (2017)[2]	Ascend Flex	100	73,4 (55-91)	28 (28)	72 (72)	70 (70)	RCA (46), massive RC tear (14), OA (28), instability arthropathy (2), RA (2), fracture sequela (8)
Goetzmann (2017)[20]	Ascend Flex	24	75,5 (59.8-82.5)	5 (21)	19 (79)	NR	RCA (13), massive RC tear (5), OA with glenoid bone loss (5), RA (1)
Schnetzke (2017)[48]	Ascend Flex	24	NR	4 (16.7)	20 (83.3)	15 (62.5)	RCA (17), post-traumatic sequelae (5), OA (2)
Merolla (2017)[36]	Ascend Flex	38	74,7 (55-91)	13 (34)	25 (66)		RCA (38)
Aibinder (2019)[1]	Comprehensive Reverse System Micro Stem	65	68,2 (31-90)	NR	NR	NR	RCA (33), OA with irreparable RC tear (25), AVN (2), post-traumatic arthritis (1), inflammatory arthropathy (4)
Dukan (2019)[13]	Ascend Flex	71	70,8	30 (44)	38 (56)	58 (82)	OA with deficient RC (71)
Raiss (2019)[42]	Ascend Flex	77*	72 (50-91)	NR	NR	NR	RCA or OA in combination with full-thickness RC tears or massive glenoid erosion (77)
Peduzzi (2019)[40]	Ascend Flex	81	76 (64-87)	NR	NR	NR	OA (81)

RSA, reverse shoulder arthroplasty; *RC*, rotator cuff; *RCA*, rotator cuff arthropathy; *OA*, osteoarthritis; *PTA*, post-traumatic arthritis; *RA*, rheumatoid arthritis; *AVN*, avascular necrosis; *NR*, not reported,
* Only radiographic results.

Five studies reported on pain improvement from preoperative until the final FU using the Constant score (CS, 0 = worst, 15 = best) as an instrument for pain determination.[5,20,36,40,48] In four of these studies the pain score improved significantly.[2,20,40,48] Weighted means changed from 5.4 to 12.9 points at final FU. The standard visual analog scale (VAS; 0 = best, 10 = worst) was used to determine pain by Merolla et al[36] who reported significant improvement (8.5 to 0.8). Pain at final FU was rated as mild/none in 97.7% of the cases by Giuseffi et al.[19]

Five patient-reported outcome scores (CS, age- and gender-adjusted Constant score [CS%], subjective shoulder value [SSV], American Shoulder and Elbow Surgeons [ASES] score, VAS) were utilized to analyze the global shoulder function preoperative and at the last FU. Seven studies used the CS,[2,5,13,20,36,40,48] and in six of those studies[19] the CS was reported to have improved significantly at final FU. Two of the listed studies additionally used the CS%[5,48] and both found significant improvement at final FU. Weighted CS means improved from 27.9 to 69.3 and weighted CS% score means improved from 22.6 to 78.4.

The SSV was analyzed in two studies,[2,48] both reporting significant improvement at last FU. Weighted means for the SSV improved from 29.3% to 74.1%.

The ASES score and the VAS score were only used by Dukan et al,[13] both showing a significant improvement at last FU (ASES 36.2 to 84.3; VAS 1.1 to 0.4).

Radiographic results

Radiographic outcome was reported for 550 shoulders with a mean FU of 32 months (range, 20 to 99.6) (Table IV). Radiographic changes were described by all studies at final FU.

Three study groups described that postoperative radiographs were performed in three rotations of the humerus (neutral, internal, external) and in a lateral/y-view.[2,13,42] The assessment of radiological changes was heterogeneous throughout the ten studies. To give an overview we categorized radiographic changes into humeral bone adaptions, component loosening and scapular notching.

Humeral bone adaptions

Bone remodeling is defined by Schnetzke et al[45] through the presence of condensation lines, cortical bone resorption or osteopenia and spot welds. Using this definition, humeral cortical thinning was found in 15 of 205 cases reported by four studies.[13,36,42,48] Condensation lines were described in four studies. Humeral condensation lines were found in 8 of 205 cases reported in two studies.[13,36] Humeral spot welds were described by two studies in a stem zone distribution model.[42,48]

Proximal bone remodeling was described in 29.5% by Giuseffi et al.[19] Bone adaptions were categorized as “high” and “low” by

Table III
Clinical outcome preoperative (pre) and postoperative (post) after short-stem RSA.

Study	Prosthesis type	Shoulders, n	FU months, mean (range)	ROM pre	ROM pre (SD)	ROM post	ROM post (SD)	Pain pre (SD)	Pain post (SD)	Outcome score pre (SD)	Outcome score post (SD)
Giuseffi (2013)[19]	Comprehensive Reverse System Mini Stem	44	27 (24-40)	Flex: 54 ER: 14	Flex: 20 ER 13	Flex: 142 ER: 45	Flex: 25 ER: 9	NR	Mild/none in 43 shoulders (97.7%)	NR	NR
Atoun (2014)[5]	Verso Reverse Shoulder Prosthesis	31	36 (24-52)	Flex: 47 Abd: 42	NR	Flex: 129 Abd: 117 ER: 51	NR	CS: 0.8	CS: 12.5	CS: 12.7 CS (%): 17.8	CS: 56.2, CS (%): 80.2
Ascione (2017)[2]	Ascend Flex	100	32,6 (24-44)	Flex: 82 ER: 5.6	Flex: 31 ER: 24	Flex: 141 ER: 25	Flex: 25 ER: 20	NR	NR	CS: 25.5 (8.8) SSV: 28	CS: 69.7 (14.4) SSV: 76
Goetzmann (2017)[20]	Ascend Flex	24	25,6* (24-30.8)	Flex: 79 Abd: 63 ER: 10	Flex: 29 Abd: 24 ER: 16	Flex: 139 Abd: 122 ER: 28	Flex: 23 Abd: 27 ER 12	CS: 3 (3)	CS: 12 (3)	CS: 22 (7)	CS: 63 (11)
Schnetzke (2017)[48]	Ascend Flex	24	25* (20-35)	Flex: 62 Abd: 59 ER: 12	Flex: 26 Abd: 27 ER: 31	Flex: 119 Abd: 125 ER: 23	Flex: 43 Abd: 41 ER: 19	CS: 5.6 (4.2)	CS: 13.7 (2.6)	CS: 21.7 (12.9) CS (%): 28.8 (17.2) SSV: 35.1 (21.4)	CS: 57.1 (18.4) CS (%): 76.1 (24.5) SSV: 66.4 (23.4)
Merolla (2017)[36]	Ascend Flex	38	29,1 (24-31)	Flex: 83 Abd: 74 ER: 0	NR	Flex: 142 Abd: 131 ER: 32	NR	VAS: 8.5	VAS: 0.8	CS: 27	CS: 71.2
Aibinder (2019)[1]	Comprehensive Reverse System Micro Stem	65	45,6* (36-99.6)	Flex: 70 ER: 24	NR	Flex: 129 ER: 40	NR	NR	NR	NR	NR
Dukan (2019)[13]	Ascend Flex	71	38,8	Flex: 89 ER: 25	Flex: 19 ER: 10	Flex: 131 ER: 36	Flex: 20 ER: 8	NR	NR	CS: 44.2 (11.2) VAS: 6.8 (1.1) ASES: 36.2 (5.3)	CS: 87.9 (11.6) VAS: 0.4 (0.9) ASES: 84.3 (9.4)
Raiss (2019)[42]	Ascend Flex	77	28 (24-48)	NR	NR	NR	NR	NR	NR	NR	NR
Peduzzi (2019)[40]	Ascend Flex	81	27,5* (23-47)	Flex: 84 Abd: 80 ER: 18	Flex: 36 Abd: 28 ER: 22	Flex: 131 Abd: 111 ER: 28	Flex: 21 Abd: 27 ER: 20	CS: 7.9 (12.2)	CS: 13.1 (3.2)	CS: 31 (13)	CS: 62 (11)
Weighted means			33	Flex: 76 Abd: 68 ER: 15		Flex: 134 Abd: 119 ER: 32		CS: 5.4	CS: 12.9	CS: 28.9 CS (%): 22.6 SSV: 29.4	CS: 69.3 CS (%): 78.4 SSV (%): 74.1

FU, follow-up; *RSA*, reverse shoulder arthroplasty; *ROM*, range of motion; *Flex*, flexion; *Abd*, abduction; *ER*, external rotation; *CS*, Constant score; *CS (%)*, age- and gender-adjusted CS; *SSV*, subjective shoulder value; *VAS*, visual analog scale; *ASES*, American Shoulder and Elbow Surgeons shoulder score; *NR*, not reported; *SD*, standard deviation.
* Reported FU for both intervention groups.

Schnetzke et al[48] and Raiss et al,[42] who found high humeral bone adaptions in 15 of 96 cases (10.5% to 17%) and low bone adaptions in 81 of 96 cases (83% to 89.6%). Both study groups used a zone distribution model to assess humeral condensation lines with most findings in the "under the stem" area. Radiographic changes where categorized into "severe" (5%), "moderate" (12%), "mild" (18%), and "no changes" (65%) in the study by Raiss et al.[42] Humeral stress shielding was observed by Aibinder et al[1] in 18% of their cases. Heterotopic ossification was described in 46 of 182 cases in three studies.[2,19,36]

Osteolysis, radiolucent lines

Humeral radiolucency/radiolucent lines were present in 25 of 345 cases, as reported by three studies.[2,13,36] Under-the-baseplate osteolysis was described in 49.4% of cases by Peduzzi et al.[40] Resorption of greater tuberosity and lesser tuberosity was each found in 5% of cases in Merolla et al.[36] Calcar resorption was present in 25% of the cases in Aibinder et al.[1]

Stem loosening, humeral component subsidence, glenoid loosening

Humeral loosening was evaluated in 338 cases in six studies,[1,2,19,20,40,48] but no study had a case of stem loosening at final FU. Glenoid loosening was found in three cases of 352 cases in two studies,[2,40] with one case undergoing revision to exchange the polyethylene insert. Subsidence was assessed in four studies with no cases of 231.[2,5,40,48]

Scapular notching

Scapular notching was present in 60 cases of 327 cases demonstrated by five studies.[2,5,19,20,36] Scapular notching was assessed according to Sirveaux et al[52] by four studies.[2,13,20,48]

Stem alignment

Stem alignment was assessed by seven studies.[1,2,13,19,40,42,48] Four of these studies categorized the alignment into well aligned, valgus, and varus deviation.[2,19,42,48] Among these studies, 196 (82%) stems were described as well aligned or in neutral position, 30 (13%) had a valgus, and 14 (6%) a varus deviation. Two studies reported about a mean alignment in 1.7° (±2.4) and 1° (±6) varus.[13,48]

Risk factors for radiographic changes/humeral loosening

Three study groups claimed that the occurrence of bone adaption is influenced by the filling ratio (FR).[13,42,48] Schnetzke et al[48] demonstrated that patients with low bony adaption after RSA had a significantly lower diaphyseal FR compared with patients with high adaptions ($P = .023$). Raiss et al[42] detected that patients with low adaptions had a metaphyseal FR of 0.68 and 0.74 in patients with high adaptions ($P = .017$). The diaphyseal FR was 0.77 in patients with low adaptions and 0.85 in patients with high adaptions ($P = .001$). The relative risk for "high bone adaptions" showed a 7.0-fold increased when the diaphyseal FR of ≥ 0.8 ($P = .001$). The study also demonstrated that cortical contact of the stem led to high adaptions more frequently ($P = .014$).

Table IV
Radiographic outcome after short-stem RSA.

Study	Prosthesis type	Shoulders, n	FU, months (range)	Humeral bone adaptions	Scapular notching	Humeral loosening	Glenoid loosening
Giuseffi (2013)[19]	Comprehensive Reverse System Mini Stem	44	27 (24-40)	Heterotopic ossifications: 18 (41%), proximal bone remodeling: 13 (29.5%)	Scapular notching: 3 (6.8%)	0	Glenoid radiolucency: 0
Atoun (2014)[5]	Reverse Shoulder Prosthesis Verso	31	36 (24-52)	Humeral radiolucency: 0, humeral subsidence: 0	Scapular notching: 2 (6%), glenoid notching: 2	NR	NR
Ascione (2017)[2]	Ascend Flex	100	32.6 (24-44)	Stem RLL: 4, humeral subsidence: 0, heterotopic ossifications: 22%	Scapular notching: 37%	0	Glenoid RLL: 2, glenoid aseptic loosening: 2
Goetzmann (2017)[20]	Ascend Flex	24	*25.6 (24-30.8)	Stem RLL: 0	Scapular notching: 3 (12.5%)	0	Glenoid loosening: 0
Schnetzke (2017)[48]	Ascend Flex	19	*25 (20-35)	High humeral bone adaptions: 2 (10.5%), low humeral bone adaptions: 17 (89.5%), humeral subsidence: 0, humeral spot welds, humeral condensation lines, cortical thinning/osteopenia	0	0	NR
Merolla (2017)[36]	Ascend Flex	38	29.1 (24-31)	humeral radiolucency: 4 (10%), humeral condensation lines: 6 (16%), humeral cortical thinning: 10 (26%), humeral spot welds: 0, humeral resorption of greater tuberosity: 2 (5%), humeral resorption of lesser tuberosity 2 (5%), heteotopic ossifications: 6 (16%)	Scapular notching: 2 (5%)	NR	Glenoid radiolucency: 0, glenoid RLL: 0
Aibinder (2019)[1]	Comprehensive Reverse System Micro Stem	65	*45.6 (36-99.6)	Calcar resorption: 16 (25%), humeral stress shielding: 12	NR	0	0
Dukan (2019)[13]	Ascend Flex	71	38.8	Stem RLL:17 (24), humeral cortical thinning: 5 (7), osteocondensation: 2	Scapular notching: 13 (18%)	NR	NR
Raiss (2019)[42]	Ascend Flex	77	28 (24-48)	No radiographic changes: 50 (65%), mild radiographic changes: 14 (18%), severe radiographic changes: 4 (5%), low bone adaptions: 64 (83%), high bone adaptions: 13 (17%), cortical bone narrowing/ osteopenia, condensation lines, spot welds	NR	NR	NR
Peduzzi (2019)[40]	Ascend Flex	81	*27.5 (23-47)	Stem RLL: 0, humeral subsidence: 0, under-the-baseplate osteolysis: 49.4%	NR	0	1
Weighted means			32				

FU, follow-up; *RLL*, radiolucent lines; *RSA*, reverse shoulder arthroplasty; *NR*, not reported.
* Reported FU for both intervention groups.

Goetzmann et al[20] found that bone resorption was associated with higher FR ($P < .001$). Patients with bone adaptation related to stress shielding had significantly higher metaphyseal filling (64% vs. 56%, $P = .026$) as demonstrated by Dukan et al.[13]

Goetzmann et al[20] reported that cortical osteolysis/proximal medial cortical bone thinning occurred in 7 cases after RSA (29.2%), but only in women ($P = .001$). Gender also seemed to influence bone adaption in the study of Raiss et al,[42] who described an association between female sex and high bone adaptions ($P = .018$).

Peduzzi et al[40] compared cases with the short stem in an anatomic configuration to cases with the short stem in a reverse configuration and found that lateral metaphyseal thinning and under-the-baseplate osteolysis was associated with the implantation of a short-stem RSA ($P = .04$ and $P < .001$).

The rates of scapular notching were evaluated by two study groups.[2,36] Merolla et al[36] reported that glenoid bone grafting did not affect the occurrence of scapular notching. However, Ascione et al[2] demonstrated a significantly lower percentage of scapular notching in patients receiving Bio-RSA (24.6% vs. 51.5%) and inferior offset glenosphere ($P = .05$). It was also found that scapular notching did not have any implication on clinical outcomes in the study. The authors reported that scapula fractures occurred in four patients with Bio-RSA compared with only one patient in the classic RSA group, which led to a higher complication rate in the Bio-RSA group (not significant).

Giuseffi et al[19] reported that 18 stems (41%) had evidence of heterotopic ossification at the inferior glenoid where the insertion of the long head of triceps was routinely released at the time of surgery. They did not find an association of heterotopic ossification with decreased postoperative ROM.

Complications and revisions

A total of 63 complications were reported for 490 shoulders in nine studies (Table V).[2,5,13,19,20,36,40,42,48] One study did not report complication and revision rates for RSA separately; therefore, it was not included in the analysis.[1] Postoperative traumatic fractures were not considered to be prosthesis related and therefore are not reported as complications in this review.

Scapula fractures were the most commonly reported complication, with nine type II fractures (acromial fracture) and 10 type III fractures (scapula spine fracture) reported by eight studies including 446 patients. Despite its frequent occurrence, only two cases required revision surgery.[2]

Infections occurred in 14 of 367 cases, with most cases leading to revision surgery (11 revisions).[4,13,36,40,42] Instability occurred in eight of 290 cases, with the need for revision surgery in seven cases.[2,5,36,41] Brachial plexus palsy occurred in three cases, with two of these cases requiring a revision with a stem exchange.[2,20] Of three humeral fractures, one had to undergo revision surgery with

Table V
Complications and revisions after short-stem RSA.

Study	Shoulders, n	Complications	Details of complications	Revisions	Treatment
Giuseffi (2013)[19]	44	3 (6.8%)	Superficial infection: 1, dislocation: 1, brachial plexus abnormality: 1	0	0
Atoun (2014)[5]	31	6 (19.4%)	Acromial stress fracture: 1, dislocations: 2, intraoperative humeral fractures: 2, intraoperative glenoid fractures: 1	2 (6.5%)	2 instabilities: reorientation of liner, osteophyte resection
Ascione (2017)[2]	100	15 (15%)	Scapula spine fracture: 4 (4%), acromial fracture: 1 (1%), infections: 4 (4%), instability: 3 (3%), glenoid aseptic loosening: 2 (2%), brachial plexus palsy: 1 (1%)	10 (10%)	1 scapular spine fracture: ORIF, 1 acromion fracture: ORIF, 3 infections: 3 single stage revisions ,3 instabilities: change to larger glenosphere and thicker PE insert, 1 glenoid aseptic loosening: change to thicker PE insert, 1 plexus palsy: stem exchange
Goetzmann (2017)[20]	24	2 (8%)	Scapula spine fracture: 1, brachial plexus palsy: 1	1 (4%)	Plexus palsy: stem exchange with humeral shortening
Schnetzke (2017)[48]	24	2 (8.3%)	Acromion fatigue fractures: 2	0	0
Merolla (2017)[36]	38	7	Scapula spine fracture: 2, acromial fracture: 1, infections: 3, instability: 1	2 (5.3%)	1 infection: 1-step revision with change to another reverse prosthesis, 1 dislocation: change to higher PE insert
Aibinder (2019)[1]	65	NR	NR	NR	NR
Dukan (2019)[13]	71	15 (21%)	Acromial stress fracture: 3, late sepsis: 2, anterior delta atrophy: 9 (12%), intraoperative partial glenoid fracture: 1	2 (2.8%)	2 infections: 2-step revision with spacer
Raiss (2019)[42]	77	6 (7.8%)	Acromial stress fracture: 1, severe infections: 2, mild infections: 2, dislocation: 1	5 (7.8%)	4 infections: change of PE liner and glenosphere, 1 instability: change to a thicker PE liner
Peduzzi (2019)[40]	81	7 (8.6%)	Scapula spine fracture: 3, infections: 1, minor wound problem: 1, glenoid loosening: 1, humeral fracture: 1	2 (2.5%)	1 infection: change of insert/glenosphere, 1 humeral fracture: change of humeral stem, ORIF
All	490	63/490 (12.9%)		24/490 (4.9%)	

PE, polyethylene; *ORIF*, open reduction internal fixation; *RSA*, reverse shoulder arthroplasty; *NR*, not reported.

open reduction and internal fixation.[40] Intraoperative fractures of the humerus and the glenoid occurred each in two cases.[5,13]

Glenoid loosening was reported in three of 352 cases with one case requiring a revision.[2] There were no cases of humeral stem loosening reported in 333 cases at final FU.

Other complications that did not require a revision surgery were anterior delta atrophy (9 cases)[13] and minor wound problems (2 cases).[19,40] Altogether, revision surgery was necessary in 24 cases. For overall pooled complication and revision rates, see Table VI.

Table VI
Pooled complication and revision rates among selected short-stem RSA studies.

Complications	n (%)
Complications all (%)	63 (12.9)
Infections	14 (3)
Scapula spine fracture/type III scapula fracture	10 (2)
Acromial fracture/type II scapula fracture	9 (2)
Instability	8 (2)
Humeral fracture	3 (1)
Glenoid loosening	3 (1)
Minor wound problem	2 (0.4)
Glenoid fracture	2 (0.4)
Brachial plexus palsy	2 (0.4)
Revision surgery	**n (%)**
Revision surgery all (%)	24 (4.9)
Revision for infection	11 (46)
Revision for instability	8 (33)
Revision for plexus palsy	2 (8)
Scapula spine fracture	2 (8)
Humeral fracture	1 (4)

RSA, reverse shoulder arthroplasty.

Discussion

The most important finding of the study was that RSA with a short stem provides good clinical outcomes but humeral bone adaptions occur frequently at short-term FU.

Clinical outcomes were reported in nine of ten studies, with ROM improving significantly in all studies. Six of the seven studies that used the CS demonstrated significant score improvement with a weighted mean comparable with standard long-stem results.[9,15]

Humeral bone adaption, or bone remodeling, is a reaction to stress shielding that causes bone narrowing with osteopenia, condensation lines around the stem and local spot welds. It is strongly associated with the press-fit implantation of standard long stems.[10,11,27,33,34,38,45,57,60]

The rate of proximal bone remodeling was described to be 29.5% in the study by Giuseffi et al.[19] High humeral bone adaptions were reported in 10.5% of cases by Schnetzke et al,[48] humeral stress shielding occurred in 18% of the cases of Aibinder et al[1] and Raiss et al[42] found severe radiographic changes in 5% of their cases with a high bone adaption rate (17%).

Standard long-stem RSA stress shielding rates at short-term FU have been reported as high as 68% to 97%.[11,27] However, there is limited literature reporting on humeral bone adaptions after standard long-stem RSA[9-11,18,27,34] and the heterogeneous evaluation methods used by the studies make it difficult to draw conclusions. Therefore, zone distribution models like the one presented by Schnetzke et al[48] and Raiss et al[42] and standardized examinations are highly recommended for future investigations.

Three study groups have suggested a relationship between the occurrence of bone adaptions and FR.[13,42,48] A relation between FR and bone adaptions was already described after short-stem TSA and discussed extensively by Schnetzke et al.[45] In theory, an implant with a shorter stem will result in a smaller portion of the proximal humerus being subjected to stress load sharing and more proximal stress conduction from the implant to the bone.[45] In a recent study by Lädermann et al,[29] a low FR was shown to be associated with greater risks of varus stem positioning, with misalignment of short stem found in 47% of the cases. Studies in this review report about lower rates of misalignment [2,13,19,42,48] but we agree with Lädermann et al[29] that misalignment of short stems may be a common, but under-reported problem.

It is also significant that aseptic stem loosening was not a matter of concern after short-stem RSA in the short-term FU. Loosening of the humeral component is defined as implant migration or a radiolucent line of 2 mm or more around the entire stem.[21,33,34,56] Six studies assessed the presence of radiolucent lines around the humeral component, reporting 25 of 345 (7%) radiolucent lines being smaller than 2 mm.[2,5,13,20,36,40] It was shown that loosening of the humeral component rarely appears in the absence of infection after standard long-stem RSA in the short-term FU. [11,27] However, low loosening rates have been observed at medium-term FU[18] and in a meta-analysis of 1,660 cemented and 805 uncemented RSA long stems by Grey et al,[23] it was demonstrated that aseptic stem loosening does play a role at long-term FU (> 5years). Although there were no cases of humeral component loosening in the ten studies with short-term FU, humeral stem loosening is possible at long-term FU.

As a third finding, scapular notching was present in 60 of 327 cases (18%) of short-stem RSA. Comparing this rate to the current literature on long-stem RSA, scapular notching was found to be present in higher rates (51% to 88%) at medium-term FU.[30,34,59] Several authors demonstrated that scapular notching has a negative impact on clinical outcomes. [31,51] Glenoid bone grafting techniques and other implantation techniques are used to reduce scapular notching in RSA[8] and in short-stem RSA.[2] Ascione et al[2] were able to demonstrate a lower percentage of scapular notching in patients receiving Bio-RSA and inferior offset glenosphere. Comparing a Grammont humeral design to short-stem RSA, Merolla et al detected lower rates of scapular notching in the lateralized short-stem group, a result they connected to the 145° neck shaft angle of the Ascend flex design.[36]

Lastly, there is a comparable overall complication rate at short-term FU between short-stem RSA and long-stem RSA. For short-term RSA we found 63 complications reported for 490 shoulders (12.9%) in nine studies.[2,5,13,19,20,36,40,42,48] Complication rates after standard long-stem RSA varied between 8.4% and 24%,[9,11,27,34] but a true comparison is difficult due to different FU rates and study designs. In our review, scapula fractures and infections accounted for most of the reported complications. This is comparable with results after traditional long-stem RSA where scapula spine fractures,[11,27] instability,[9,27,34] and deep infection[9,27] were frequently reported. Based on a systematic review by King et al,[28] the rate of acromial and scapula fractures after RSA is 2.8%. This is potentially due to excessive tensioning of the deltoid muscle causing subsequent inferior stress on the acromion, weakening of the scapula through drill holes, and a lateralized glenosphere design. One potential risk factor for acromial or scapula spine fractures may be an increased humeral offset caused by implanting short stems with an onlay technique as recently described by Haidamous et al.[24] However, we believe that positioning of the stem and inclination angle are important factors to compensate for these effects. It is concluded that scapula fractures are a general problem of RSA rather than a unique complication of short-stem RSA.

With limited long-term FU, it is not possible to predict the rate of failure or failure due to bone adaptation for short-stem implants in primary RSA surgeries. Clinical and randomized trials for short-stem RSA and more long-term FU are crucial for better understanding the potential risks and benefits.

Limitations

This study is a systematic review of mostly level IV studies and is therefore affected by the limitations of each individual study. Although all ten studies aimed to report exclusively on uncemented short stems, cemented stems were used in 31 cases and long stems were used in five cases. These results were included within the final analysis. Outcomes after short-stem RSA with minimum one-year FU are not directly comparable to the results after standard long-stem RSA as implant designs, FU, inclusion criteria, and measurement of bone adaptions vary among these studies.

Conclusion

Good clinical results that are comparable with long-stem RSAs are reported at short-term FU for short-stem RSAs. Humeral bone adaptions occur frequently but aseptic stem loosening is not a matter of concern at short-term FU. An area of clinical importance that might be potentially underreported is the relation between filling ratio and stem alignment in short-stem RSA.

Conflicts of interest

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